# CHAPTER 9
# Interactions Between Capture Fisheries and Aquaculture

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*The study of interactions between aquaculture and capture fisheries is important as they drive many of the changes that are currently transforming the seafood sector. A better understanding of these interactions brings important lessons for the improved management of wild fishery resources. This chapter explores in some detail the nature of these interactions and examines their implications for the future of both wild and farmed seafood sectors.*

## Introduction

As activities that take place in aquatic environments and rely upon aquatic resources, aquaculture and capture fisheries interact at many different levels. Some of these interactions are antagonistic, but in many cases synergistic relationships have also emerged. Interactions are determined to a large extent by both technological and institutional differences between the two sectors. Aquaculture normally involves an acceptance of ownership of products and production facilities, while capture fisheries exploit common property (De Silva et al., 2003). Capture fisheries typically utilize regulated open-access resources with human intervention occurring primarily at the harvesting stage. Aquaculture, in contrast, involves systems in which the grower has a large degree of control over both the cultured organism and the culturing environment. Practices such as culture-based or enhanced fisheries draw elements from both activities.

The largest influence of aquaculture on wild fisheries has probably occurred through international trade and the market. Aquaculture has: a) influenced prices negatively through increased supply and positively through the development of new markets (e.g., salmon and catfish); b) changed consumer behavior; c) accelerated globalization of the industry; d) increased concentration and vertical integration in the seafood sector; e) resulted in the introduction of new product forms; and f) significantly changed the way seafood providers conduct business.

The growth of aquaculture has stimulated the traditional wild fisheries sector to improve product quality in terms of freshness, consistency, handling, and processing. In some cases, aquaculture has provided incentives for fisheries management to become more efficient. This growth has also created a backlash of criticism from the wild fisheries sector (and environmental groups) through the media and, in several cases, has been met with increasingly restrictive international trade barriers (e.g., salmon, shrimp and catfish).

A second group of interactions is concerned with the flow of environmental impacts between the two sectors. These impacts, in turn, may have economic consequences for both aquaculture and wild capture fisheries. At this level, aquaculture has: a) directly influenced fish stocks through its use of wild fish stocks for inputs, such as feed; b) influenced fish stocks through intentional releases (salmon stock enhancement) or through unintentional escapes; c) displaced wild fish through its use of habitat and, in some cases, enhanced fisheries habitat (e.g., some oyster operations); and d) influenced and been influenced by wild fish stocks through transmission of diseases and parasites.

The study of interactions between aquaculture and capture fisheries is important as they drive many of the changes that are currently transforming the seafood sector. A better understanding of these interactions brings important lessons for the improved management of wild fishery resources. This chapter explores in some detail the nature of these interactions and examines their implications for the future of both wild and farmed seafood sectors.

## Aquaculture, fisheries, markets and trade

Whether aquaculture and fisheries behave as competitive or complementary activities is a research question that has received attention in recent times. Judgments regarding the positive or negative nature of these interrelations are likely to be influenced by the perspective of the different stakeholders: aquaculturists, fishermen, fisheries managers, traders, consumers, or environmentalists. It must be recognized, nevertheless, that aquacultural development has been stimulated by the overfishing of wild stocks, which has resulted in the inability of the wild sector to meet the growing demand for wholesome seafood products. Salmon farming emerged in the 1980s as wild stocks of Coho and Chinook salmon in North America dwindled and Atlantic salmon stocks were threatened in both America and Europe due to overfishing and loss of habitat. Growth in catfish and tilapia aquaculture has satisfied market demand in the whitefish complex as harvests of the wild product have decreased considerably. Falling supplies of wild groundfish have also stimulated commercial production of farm-raised cod in Norway. In each of these cases, the aquaculture sector has emerged to increase fish supplies, minimize environmental shocks, control fish stocks and growth rates, and manage to meet the demands of the market. Aquaculturists want to take control of production and marketing. They tend to do this through ownership, information and technology (Anderson, 2002).

The emerging aquaculture sector tends to be more forward looking, faster-growing, innovative, international, and control-oriented. It is shaping the future seafood sector through market, trade, and product interactions. Over the last few decades, aquaculture has:

- influenced prices through increased supply;
- changed consumer behavior resulting in the development of new markets;
- accelerated globalization of the industry;
- increased concentration and vertical integration in the seafood sector;
- resulted in the introduction of new product forms and improved quality and consistency;
- influenced the sector to become more forward-thinking and market driven;
- reduced price uncertainty and risk.

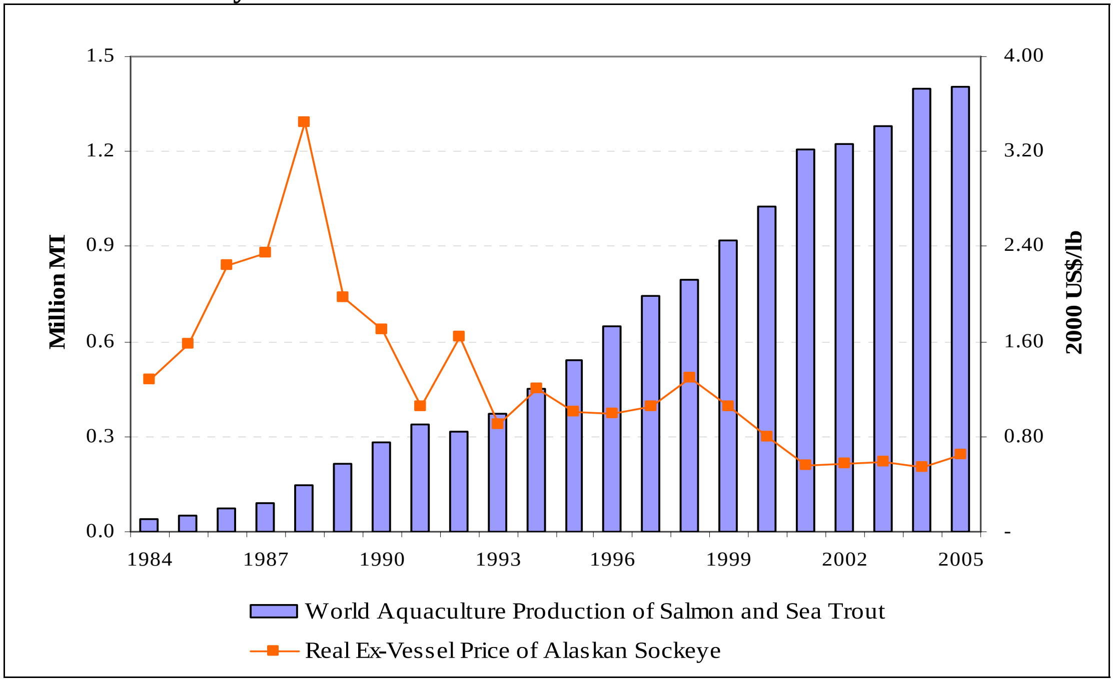
Some of these interactions are discussed more thoroughly in the following sections.

*Price Interactions*

The economic impacts of aquaculture on capture fisheries are more evident in the case of species such as shrimp and salmon, where markets for wild species were well established prior to the emergence of the global aquaculture sectors. The most visible impact concerns declines in the prices of wild-caught fish brought about in part by increased supplies of farmed fish, because farmed and wild products interact as close substitutes (Figures 9.1 and 9.2).

Figure 9.1 illustrates the evolution of real ex-vessel prices for Alaskan sockeye salmon during the last 20 years. Real prices consistently rose during the early and mid-1980s, but declined precipitously in 1989 and subsequent years. The fall in prices was closely related to record landings in the Alaska fisheries throughout the 1990s, as well as increased supplies from an emerging salmon aquaculture industry. The ex-vessel price in 2005 (in 2000 U.S. dollars) was only $0.65/lb, equivalent to only 65% of the prevailing price in 1995, and barely 19% of the 1988 price.

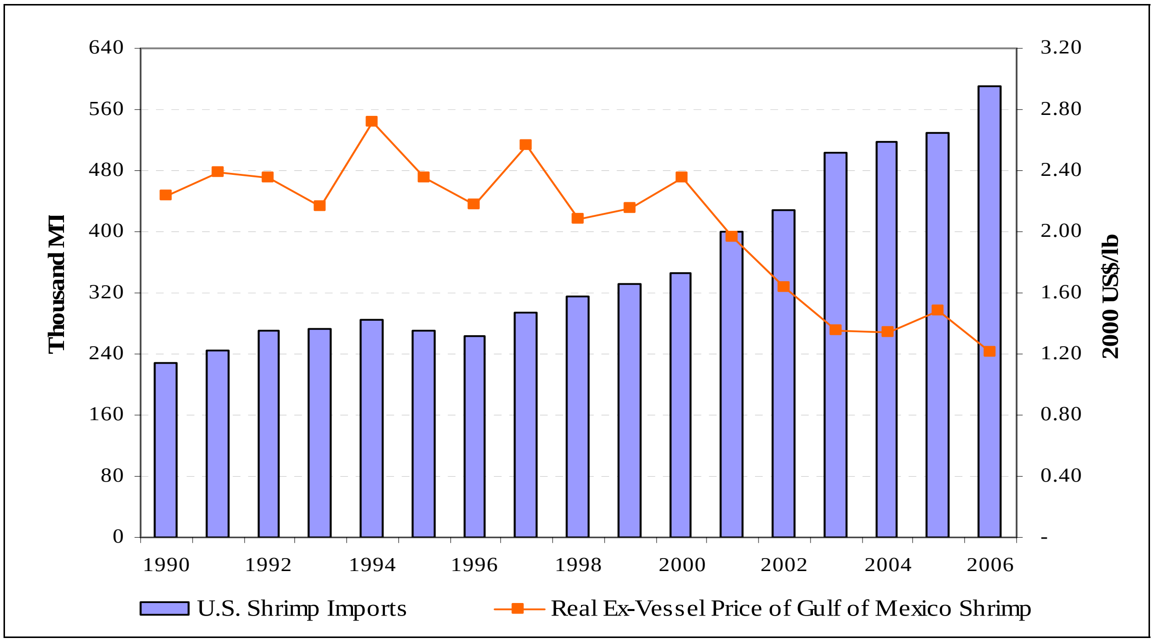
**Figure 9.1. Comparison of world salmon aquaculture production and real ex-vessel price of Alaskan sockeye salmon.**




Sources: FAO, 2007; ADF&G, 2007

Increasing shrimp imports to the U.S. market have had a similar impact on the ex-vessel prices of wild shrimp caught by the domestic fleet (Figure 9.2). Most of imported shrimp (around 70-80%) is produced in farms on the tropical regions of Asia and Latin America. The average ex-vessel price (2000 U.S. dollars) of the three most important domestic wild species (white, brown, and pink) oscillated around $2.40/lb during the late 1980s and the 1990s. However, prices have fallen sharply since 2001. By 2006, the average real ex-vessel price was $1.22/lb, around $1.15 less than the real price in 2000. Domestic fishermen blamed increased imports of farmed shrimp for the faltering prices. Seeking relief from allegedly unfair trade practices, the U.S. fishing industry filed an antidumping suit against the six most important suppliers of shrimp to the U.S. market (Thailand, China, Vietnam, India, Brazil, and Ecuador) in December, 2003. In its final determination, the U.S. International Trade Commission ruled in favor of the domestic industry, and antidumping duties of various magnitudes were levied against the six subject countries (USITC, 2005).

**Figure 9.2. Comparison of U.S. shrimp imports and real ex-vessel price of domestic Gulf of Mexico (brown, pink, and white) shrimp. Approximately 70-80% of the shrimp imported into the U.S. are farm-raised.**




Source: USDC/NMFS Foreign Trade Database, 2007; USDC/NMFS Commercial Fishery Landings Database, 2007.

It should be noted that aquaculture production of salmon and shrimp has been increasing steadily, even in the face of declining prices. Guttormsen (2002) explains that such a phenomenon is evidence of productivity gains in the aquaculture sector, meaning that expansion has been possible due to the ability of farmers to substantially lower production costs. The difference in the structure of costs between aquaculture and wild fisheries has important implications. In the traditional fisheries, the primary costs are labor, fuel and fleet maintenance. In the aquaculture sector, the primary costs are feed and fingerlings. This distinction is important, as aquaculture has immense opportunities to reduce costs through genetics research and feed substitutions. In contrast, fisheries have less room for cost improvement unless a move is made towards more efficient management; e.g., rights-based fishing (Anderson, 2003). All of this comes down to a matter of better management, biotechnology and related factors. The most impressive achievements have been attained in salmon aquaculture, but there is still much room for improvement with regard to production of tilapia and other new species. This trend will enable aquaculture to continue recording gains in market share at the expense of wild-caught species.

While negative price interactions are generally more visible, some positive price influences between aquaculture and wild fisheries have also been observed. Positive interactions emerge when the aquacultured product is introduced into new markets and creates additional demand for both farmed and wild species. For example, prior to the advent of salmon farming in the 1980s, salmon consumption in the U.S. was limited seasonally and regionally - primarily to the Pacific coastal areas. The growth of aquaculture in Norway, Canada, and Chile led to consistent supplies of fresh, high-quality salmon in the untapped South and Midwest regions. The increased availability resulted in new demand for both farmed and wild salmon in these regions. The case of catfish is similar. Prior to modern production in farms, catfish was generally regarded as a low-quality wild product with consumption restricted to the poor areas of the rural South. The consistent delivery of a high-quality product from catfish farms turned around this perception over a few decades, with concomitant increases in price. Nowadays, catfish is routinely included in the list of Top 10 seafoods in the U.S. (NFI 2007).

In addition to the price interactions, it has been suggested that aquaculture may contribute to the recovery of overexploited wild stocks, as reduced prices lead to lower fishing effort. These interactions were formally analyzed by Anderson (1985) and Ye and Beddington (1996). Anderson's analysis showed that the entry of aquaculture reduces effort and increases total supply from open-access fisheries while raising natural fish stocks. Because aquaculture enhances efficiency in the capture fishery while increasing availability of fish to consumers, aquaculture development is regarded by some as a much more effective management tool relative to traditional measures of effort control. In a related analysis, Green and Kahn (1997) found similar results and used them to argue for public subsidization of aquaculture.

*<u>Econometric Models and Time Series Analyses</u>*

A number of studies have examined market interactions between aquaculture and fisheries by estimating demand equations for a specific group of commodities and testing whether cross-price effects occur. The general idea is to probe the existence of an underlying marketplace constituted by a group of commodities consisting of both farmed and wild-caught species. The group of commodities competes in the same market because consumers may substitute goods. The cross-price effects estimated from the system of demand equations provide a measure of the degree of substitution among competing goods.

In the late 1980s and early 1990s, a number of empirical analyses of the international salmon market estimated demand functions for both wild-caught and farmed species. Herrmann, Mittelhammer and Lin attempted to describe the patterns of salmon trade between North America, the European Community (EC), Japan, and Norway through several econometric models (Herrmann, 1993; Herrmann et al., 1993; Lin et al., 1989; Herrmann and Lin, 1988; Lin and Herrmann, 1988). In general, these studies reported large income and own-price elasticities, consistent with the notion of salmon as a luxury food item previous to the revolution brought upon by salmon aquaculture. The cross-price elasticities between farmed Atlantic and wild Pacific species revealed a significant substitute relationship; however, the degree of these interactions varied widely among studies. The most recent of these analyses (Herrmann, 1993) reported an own-price elasticity of -1.76 for Norwegian farmed Atlantic salmon in the U.S. market, with an income elasticity of 1.69. The cross-price elasticity with respect to North American Pacific high-valued salmon (Chinook, Coho, and Sockeye) was estimated to be 0.72. This study was based on data from the period 1982-1991.

Although the econometric models of Herrmann and his collaborators established a connection between farmed and wild salmon in the world markets, they failed to capture the full extent of changes caused by the rapid development of aquaculture. Wessells and Anderson (1992) indicated that the demand curves estimated in these studies are actually capturing a series of demand shifts of a growing market. Because the supply of Norwegian farmed salmon grew at such a rapid pace during the 1980s, demand for the product expanded from exclusive, up-scale restaurants to other restaurants and supermarkets. The aggregate elasticities estimated by Herrmann do not account for the fact that different sectors (retailing, restaurants) may have different demand elasticities, which were evolving during the study period due to demand shift and expansion into new markets.

With regard to shrimp, Keithly et al. (1993) conducted a comprehensive econometric analysis of trade flows in the world market using annual data from 1965 through 1989. Their analysis was based on an examination of the U.S. and Japanese shrimp imports markets in a simultaneous-equations framework. The model consisted of five structural equations: two of the equations defined import demand relationships for the U.S. and Japan; another two equations defined export supplies to the U.S. and Japan; and a fifth equation defined demand for U.S. warmwater shrimp, caught by the domestic fishing industry. The U.S. warmwater shrimp demand equation in the model specified the real U.S. dockside shrimp price to be negatively related to U.S. warmwater catch, U.S. beginning-of-the-year inventories, and U.S. imports. The level of U.S. imports (consisting primarily of aquacultured product) was determined endogenously in the model. Results indicated that U.S. warmwater catch and imports have similar impacts on dockside price because of their high degree of substitutability. A 10-million pound increase in imports was found to lead to a $0.084 decline in real dockside shrimp price, with all other factors held constant.

Given the expected increase in world supply of farmed shrimp during the 1990s, Keithly et al. (1993) correctly anticipated that expanding imports of aquacultured shrimp would contribute to lower dockside and farm-gate prices of U.S. warmwater shrimp (wild and cultured). The authors also predicted that the U.S. fishing industry would respond to an increasing flow of imports by lobbying in favor of restrictive trade measures such as tariffs or quotas, in an attempt to increase prices. Keithly argued against such measures, as the common property nature of the Southeast shrimp fishery suggested that any increase in price would be followed by an expansion in shrimping effort. This expansion would drive industry profits, excluding opportunity costs, back toward zero.

In addition to estimating demand functions and cross-price elasticities, substitution relationships among two and more products can also be tested by examining the properties of the respective price-time series through cointegration techniques. The general idea is that, provided the products are substitutes for each other, prices will be integrated and will tend to move together. Thus, if the supply curve for farmed fish shifts out (meaning that the price of farmed fish falls) and there is a substitution effect between farmed and wild products, the demand schedule for wild fish shifts and the price will change in the same direction as the price of farmed fish. At most, the price of wild fish can shift by the same percentage as the price of farmed fish, making the relative price constant. When this occurs, it is said that the "Hypothesis of One Price" holds (Asche et al., 2001).

Most cointegration-analysis studies examining the price interactions between wild and farmed species have been conducted with respect to salmon. Results of these studies are consistent with previous demand analyses and indicate that different salmon species and product forms are close substitutes (e.g., Asche et al., 1999; Clayton and Gordon, 1999; Gordon et al., 1993). An important conclusion is that increased production of farmed salmon has had a substantial impact on the markets and prices for wild Pacific salmon. Asche et al. (1999) attributed declining prices in the world salmon market throughout the 1990s to the remarkable increases in productivity in the farmed salmon industry. Similarly, Clayton and Gordon (1999) supported the existence of an equilibrium price system in the U.S. market for farmed Atlantic and wild Chinook and Coho salmon.

There is little evidence that farmed salmon competes with species other than wild salmon. In their analysis of the Spanish seafood market, Jaffry et al. (2000) concluded that salmon is at best only a weak substitute for tuna, hake, and whiting. In general, salmon does not seem to compete with the species constituting the global whitefish market (Asche et al., 2001). However, other emerging aquaculture species such as tilapia and catfish have made significant inroads in the whitefish market (Picchietti, 1996; Barnett, 1990).

Similar analyses have also been conducted to examine price interactions between farmed and wild-caught shrimp. Béné et al. (2000) conducted a series of cointegration tests with data from the French market and concluded that the price series of the (farmed) black tiger shrimp and the (wild-caught) French Guyana (FG) brown shrimp were cointegrated, with the black tiger shrimp acting as a market leader for the FG shrimp product. Despite its perceived lower culinary quality, farmed shrimp emerged as the “leader” product in the French market over the last 15 years due to its consistent supply and year-round availability. The authors suggested that the only way for local FG exporters to eliminate the exogenous influence of the black tiger shrimp would be to “cut” the relationship that links the price of the FG product to that of the farmed shrimp. This could possibly be achieved by taking advantage of the superior culinary quality of the brown shrimp to create a niche market where the FG product could be supplied without having to compete against the farm-raised shrimp.

More recently, Vinuya (2007) used cointegration analysis to examine the degree of market integration in world shrimp markets. His results indicated a strong linkage among the Japanese, U.S., and European markets. The analysis concluded that the recent antidumping tariffs levied against the six major exporters to the U.S. market will have little long-term effect on domestic shrimp prices, as exporters not targeted by the antidumping tariffs realign their supplies from the other marketplaces (E.U. and Japan) towards the U.S. Recent empirical evidence confirm these findings.

*Changes in the Patterns of Seafood Consumption in the U.S.*

An examination of seafood consumption in the U.S. illustrates the influence of the aquaculture sector on seafood availability, changes in consumer behavior, and increasing concentration on fewer species. First, per-capita consumption of aquaculture species has increased remarkably over the last two decades (Table 9.1). In 1987, three “aquaculture” species—shrimp, catfish, and salmon—accounted for only 21% of U.S. consumption of seafood products. Per-capita consumption of wild-caught species such as cod, Alaskan pollock, and flatfish exceeded consumption of either catfish or salmon. By 2006, the ranking of the “Top Ten Seafoods” had shifted remarkably toward species of aquaculture origin. Shrimp, salmon, catfish, and tilapia accounted for 50% of the U.S. consumption of seafood. Salmon, in particular, recorded impressive gains: per-capita consumption rose by nearly 360% between 1987 and 2006, exceeding consumption of more traditional capture species such as cod, pollock, and flounder.

Tilapia has also made notable gains. Practically unknown in the U.S. market until the late 1990s, it became widely available in the last few years. By 2006, it was the fifth most consumed species, displacing competing species in the whitefish market segment such as cod and groundfish.

Another important trend is that seafood consumption in the U.S. is becoming concentrated on fewer species. The top five species accounted for 72% of consumption in 2006; in comparison, they accounted for only 56% of consumption just two decades ago. The top ten species comprised 71% of consumption in 1987; they now represent 90%.

The trends of falling prices and increasing concentration of consumption are explained by the fact that growing markets and growing trade will be secured by those who can consistently deliver a high-quality product at stable or declining costs. In the seafood sector, this is what aquaculture producers have been doing for the past few decades. It can also be argued that sector diversity in the future is going to come from the “sauce” (i.e.; the value-added component of the fish) and from image issues such as ecolabeling, rather than being created through the production of a large number of species (Anderson and Valderrama 2007). Thus, despite the fact that hundreds of different species are harvested - and will continue to be harvested - around the planet, in proportional terms more and more of the supply is going to be concentrated in fewer and fewer species. Likewise, more and more of the diversity is going to come from the marketers because, as they take control of and manage the fish, they can market it better and start selling additional attributes. By contrast, the traditional fisheries sector is going to experience many more difficulties in this category. Aquaculture operations tend to be managed for production and marketing control. Conversely, the wild sector is managed towards restricting access and harvesting the ‘right’ amount to meet conservation goals. However, they are still failing to manage for quality and the market; yet, it is clear that the sector that manages for these two factors will attain greater market success.

The specific cases of salmon and tilapia exemplify the points made earlier. Farmed salmon production already accounts for over 70% of world supply, while the capture sector’s harvest has remained relatively stable (Knapp et al., 2007). Regarding U.S. salmon imports, most of the growth in recent years has come in the form of boneless, skinless fillets produced primarily in nations with significant aquaculture industries. A natural consequence of having an industry where production systems are more highly controlled is that more value-added processing activities can occur. The industry is currently dominated by portion-control, value-added products. The recent negative media campaigns against salmon aquaculture appear to have had some limited impact on demand (an analysis of these developments is beyond the scope of this chapter). For the purposes of this discussion, the point that must be emphasized is that salmon aquaculture has moved forward and gained market share despite the negative media; yet there is still room for wild salmon in both the low-end (pink and chum salmon) and the specialty/premium (chinook, coho and sockeye) segments.

Tilapia also supports strong aquaculture industries in developing countries (Egypt, Philippines, Indonesia, and China). As observed previously with salmon, U.S. imports of tilapia are experiencing a shift from whole to processed forms. Tilapia is seen as a substitute for flounder, snapper and all types of whitefish. In addition, tilapia is seen favorably by many environmental groups.

**Table 9.1. Per Capita Consumption of Seafood Species in the U.S. Species for which a Vast Majority of Supply Comes from Aquaculture are Shown in Bold Font.**

| Ranking | 1987 | Pounds | 2006 | Pounds | Percent Change |
|---|---|---|---|---|---|
| **1** | Tuna | 3.51 | **Shrimp** | 4.40 | +92% |
| **2** | **Shrimp** | 2.29 | Canned tuna | 2.90 | -17% |
| **3** | Cod | 1.68 | **Salmon** | 2.03 | +359% |
| **4** | AK Pollock | 0.88 | Pollock | 1.64 | +86% |
| **5** | Flatfish | 0.73 | **Tilapia** | 1.00 | N/A |
| **6** | Clams | 0.66 | **Catfish** | 0.97 | +63% |
| **7** | **Catfish** | 0.60 | Crab | 0.66 | +101% |
| **8** | **Salmon** | 0.44 | Cod | 0.51 | -70% |
| **9** | Crab | 0.33 | Clams | 0.44 | -33% |
| **10** | Scallops | 0.33 | Scallops | 0.31 | -8% |
| | Other | 4.76 | Other | 1.68 | -65% |
| **Total** | | **16.20** | | **16.50** | **+2%** |

Source: NFI (2007).

**Aquaculture and fisheries interactions through the environment**

Aquaculture and fisheries interact in several ways in the aquatic ecosystem. For example:

- aquaculture can influence fish stocks through its use of wild fish stocks for inputs, such as feed, broodstock or juveniles;
- aquaculture and wild fish stocks can influence each other through disease transmission and other related interactions;
- aquaculture can influence wild fish stocks through intentional releases (e.g., salmon enhancement) or through unintentional escapes;

- aquaculture can displace wild fish through its use of habitat or, in some cases, it can enhance fisheries habitat (e.g, the infrastructure of oyster farms create oyster reefs).

A few examples will be mentioned to illustrate each of these interactions individually.

*Use of Wild Fish Stocks as Inputs*

Aquaculture can influence fish stocks through its use of wild fish stocks for inputs. One of the most controversial examples concerns the use of small pelagic fishes for fishmeal and fish oil. The growth of aquaculture, in particular the farming of carnivorous fishes, has had a direct impact on the demand for fishmeal and fish oil. Fishmeal prices have traditionally traded in a range of two to three times the price of soymeal; however, fishmeal has traded recently at levels more than six times the price of soymeal. The traditional relationship between fishmeal and soymeal has changed substantially. Empirical evidence indicates that the increased relative price of fishmeal and fish oil represents an important structural shift (Kristofferson and Anderson, 2006). If fisheries are well managed, this implies an opportunity for the wild fisheries sector to increase net revenue. On the other hand, if fisheries are poorly managed, this implies increased risk of overfishing. In either case, the increased relative price for fishmeal and fish oil presents an incentive for innovation. In the specific case of salmon aquaculture, this phenomenon has led to the rapid development of new feed formulations and declining feed conversion ratios.

Another way aquaculture uses wild fish stocks for inputs is when it utilizes wild juveniles for growout. For example, tuna farmers in Australia, Mexico and the Mediterranean capture wild juveniles to be fattened in aquaculture cage systems. At its beginnings, the modern farmed shrimp industry was heavily dependent on broodstock and post-larval shrimp from the wild fisheries. The farmed oyster and mussel industries depend heavily on wild seed. If not managed correctly, the extraction of inputs could have negative effects on wild fish stocks. However, positive effects are also possible: the use of wild seeds for oyster and mussel farming may actually help increase the stock of oysters and mussels by increasing survivability.

*Issues Regarding Invasive Species and Two-way Transmission of Parasites and Diseases*

Aquaculture and wild fisheries have influenced each other through the transmission of diseases and parasites. In addition, many cases of introduction of nonnative species have involved aquacultured organisms. Oysters provide a useful example in this regard (NRC 2004). In the U.S. East Coast, the oyster disease MSX was introduced from Asia (by means of a carrier agent not yet conclusively determined) and it contributed significantly to the decline of oysters, especially in Chesapeake Bay. Another oyster disease, Bonamiosis, was introduced into France by oysters imported from North America. This introduction contributed considerably to the rapid decline of the French oyster farming industry in the 1970s. In both cases, part of the solution involved the introduction of oysters from Asia which were naturally resistant to the disease. Today the French industry is dependent upon *Crassostrea gigas*, an oyster from Asia, and U.S. officials are considering introducing the farmed Asian oyster, *C. ariakensis*, into the Chesapeake Bay. In both cases, the unfortunate invasions of introduced diseases have resulted in the use of farmed nonnative organisms to mitigate the problem.

Despite media attention to concerns related to the introduction of nonnative species, this type of introduction is common. White shrimp (*Penaeus vannamei*) from South America have been introduced into Asia because they are resistant to the White Spot disease and they are easier to grow than the native black tiger shrimp. Salmon have been introduced into Chile, New Zealand and Australia, and this introduction has resulted in substantial industries in these countries. The U.S. has introduced channel catfish (*Ictalurus punctatus*) into China. Tilapia, originally from Africa, has been introduced into nearly all tropical regions in the world.

*Release of Individuals from Aquaculture Facilities*

Aquaculture has also been used to replenish or enhance fisheries through purposeful release of juvenile or adult fish. For example, the Japanese chum salmon fishery is almost exclusively dependent upon hatchery-based salmon. In Alaska, approximately 40 percent of the state's salmon harvest is dependent upon hatchery-based fisheries (Knapp at al., 2007). However, although hatchery (aquaculture)-based capture fisheries may result in increased harvest, they also may facilitate inefficient harvest practices and create problems with genetic diversity and the integrity of truly wild stocks (Hilborn 1992).

*Influences on Habitat*

Aquaculture practices have had some extensive influence on habitat. For example, pioneering shrimp farms negatively impacted mangrove forests in tropical countries. In some locations, excessive finfish cage culture has resulted in the destruction of benthic habitat and created pollution. But there are also examples of positive aquaculture influence on habitat. The relocation of shrimp farms to zones above mangrove forests has paralleled increases in mangrove cover areas (Fast and Menasveta, 2003; Lutz, 2001). Oyster culture has contributed positively to reef development, which increases the diversity of fish in the area. Net pens also create habitat for marine species and act as fish aggregating devices. In a recent study, Rensel and Foster (2007) quantified the types and volumes of biocolonization at a commercial net-pen fish farm site in North Puget Sound in Washington State. The study showed that a typical fish pen system is populated by a diverse group of over 100 species of seaweeds or invertebrates, providing a locally important component of the food web.

Many of the conflicts concerning habitat use, siting of aquaculture facilities, and other environmental interactions can be addressed through integrated ecosystem-based management approaches to aquaculture development. McVey et al. (2006) and other authors (Dumbauld et al., 2006; Bridger, 2004; Cicin-Sain et al., 2001) offer valuable insights on how this could be achieved.

## Competition for ocean space

Space-related conflicts between aquaculture and commercial fisheries have been reported in several locations around the world. For example, in the early 1990s, local fishermen from the west coast of Ireland perceived that the expansion of salmon farms resulted in an increasing number of restricted areas for fishing (Steins, 1997). The fishermen safeguarded access to their historical fishing grounds by forming a shellfish cooperative to secure aquaculture licenses. Similar conflicts have also been reported in Norway between aquaculture and commercial herring fisheries (Doksroed, 1996). In the U.S., the siting of an experimental aquaculture grow-out facility for sea scallops off the coast of Martha’s Vineyard, Massachusetts, found strong opposition from local commercial fishermen who argued that the proposed location would hamper lobster fishery activities (WSC, 1998).

Despite the potential for conflicts, adequate coastal zoning management can lead to the development of synergies between aquaculture and traditional fisheries. In areas with declining wild catches and increasingly restrictive fishery regulations, aquaculture production may help keep waterfronts, docks, processing facilities, and cold storage units operating. One of the most successful cases of integration has been reported in Florida, where inshore fishermen forced out of business through legislative action entered into hard clam aquaculture with relative success (Barnaby and Leavitt, 2001). Open-ocean aquaculture may also provide unique opportunities for commercial fishermen either as a new occupation or a business that could complement their fishing practices since they already own vessels and have the maritime skills and knowledge of local oceanic and weather conditions. In fact, the pioneering offshore operations in the U.S. (in Hawaii and Puerto Rico) were started by individuals with commercial fishing backgrounds (Rubino 2007).

## Conclusions

This major ideas presented in this chapter are summarized below.

- One of the most important incentives for aquaculture development came from the failure of wild fisheries to meet market demands.

- Aquaculture development has led to changes in fisheries:
    - through competition (supply).
    - by developing new technology (hatchery-based fisheries).
    - by example (quality control).
    - by creating new demand – both for inputs (fishmeal) and outputs (seafood).
- There will be increases in per-capita seafood consumption; however, consumption will be concentrated on fewer species, with diversity coming in the “sauce” and with labeling issues, such as organic production and ecolabeling.

- The growth of aquaculture parallels a shift in the market towards value-added products. Technology, innovations, better nutrition, and disease management will continue to reduce costs in aquaculture. Lower production costs will increase supply from aquaculture and hold prices down for all fish. The trend towards value-added creation will drive processing to countries where labor costs are low.

- The potential constraints for aquaculture development, in particular fishmeal usage, will largely be circumvented by new technology and substitution.

- Aquaculture will dominate the commodity markets, but there will be increasing opportunities for wild market products in the upper-end segments, especially the niche markets.

- In the long run, all significant commercial seafood supplies will come from one of three sources:
  - Fish farms/aquaculture;
  - Aquaculture-enhanced fisheries;
  - Fisheries that adopt efficient management systems. These systems should clearly define rights and responsibilities and be market and product-quality driven.

- Many of the space and habitat-related impacts of aquaculture development on traditional fisheries can be reduced or eliminated altogether through adequate siting and zoning of aquaculture areas. The principles of ecosystem-based management and Best Management Practices (BMPs) offer useful guidelines for future aquaculture development.

- As fishery regulations become overly restrictive in certain areas, reducing fishing times and employment in the fishing sector, a major challenge for fishermen is to figure out how to use aquaculture as a complement to their wild catch and/or income. There have been a few success stories of fishermen transitioning into the aquaculture sector. These stories can be used as case studies to help other fishing communities adjust to the changing regulatory and market conditions. Given the set of skills they already possess, some fishermen may be well positioned to participate in the emerging open-ocean aquaculture sector.

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